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STUDY OF THE AUGUST 1972 SOLAR PROTON EVENTS: A FLUX INTENSITY PARADOX

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Abstract

The solar particle event episodes that occurred during August 1972 resulted in unusual flux distributions in space. From the aspect of observing spacecraft, this was an Eastern hemisphere event sequence for the earth and a Western hemisphere event sequence for the Pioneer 9 spacecraft (located at 0.77 AU, 46° east of the sun-earth line). For the solar flare initiated particle events on 2 August, the particle flux observed by the Pioneer 9 spacecraft was higher than that observed by earth-orbiting spacecraft as would be expected. However, for the 4 August 1972 event the flux observed at the earth was higher than observed at the Pioneer 9 spacecraft, contrary to the expectations from flux gradients in the solar corona and space. This apparent interplanetary propagation anomaly is attributed to the shock re-acceleration of the solar protons with a limited spatial extent not yet fully understood.

Background. The "classical" or expected characteristics of solar particle events near one AU is that an observer who is connected via the interplanetary magnetic field line to the heliographic location of the flaring region will generally observe the maximum possible particle intensity. An observer whose interplanetary magnetic field connection is at some other heliocentric location would observe a flux that has been attenuated by propagation through the coronal gradient between the flare position and the foot point of the Archimedean spiral path from the sun to the detection position in space. In terms of an observation location near 1 AU in space, positions east (in the sense of the solar rotation) of the heliolongitude of the flare site generally observe more flux than positions west of the solar flare site.

The Circumstances in August 1972. Having described the normal or expected situation, we will now describe the circumstances leading to the flux paradox that occurred in August 1972. The solar active region was located at eastern heliographic longitudes, so from the aspect of the earth this was an eastern hemisphere event sequence. During this time the Pioneer 9 spacecraft was at 0.77 AU, 46° east of the sun-earth line, so from the aspect of the Pioneer 9 spacecraft this was a western hemisphere solar flare event sequence.

There were four major solar flares that all had the classical characteristics associated with the generation of major interplanetary shocks and proton acceleration into the interplanetary medium. At the position of Pioneer 9 there were four distinct interplanetary shocks, one associated with each solar flare. At the position of the earth, there also were four dis-

ever, at the more distant position of the Pioneer 10 spacecraft (2.2 AU, ESP -45°) only three shock sequences can be identified; this is now recognized as a natural consequence of one shock overtaking another. We have listed the speed of each shock in the form of a blast wave equation (Smart and Shea, 1985) in Table 1.

MAJOR EVENTS DURING 2 TO 8 AUGUST 1972

Solar Flare	Type II	Equation	detection time	
2 Aug 13N 36E	0324	$V = 516\ r^{-0.5}$	3 Aug 0440 (P9) 6 Aug 1520 (P10)	4 Aug 0119 (E)
2 Aug 13N 28E	2040	$V = 623\ r^{-0.5}$	3 Aug 1117 (P9) 6 Aug 2230* (P10)	4 Aug 0221 (E)
4 Aug 15N 9E	0621	$V = 1275\ r^{-0.5}$	4 Aug 2323 (P9) 6 Aug 2230* (P10)	4 Aug 2054 (E)
7 Aug 14N 38W	1519	$V = 549\ r^{-0.5}$	9 Aug 0707 (P9) 13 Aug 2054 (P10)	8 Aug 2354 (E)

* Shocks have merged

The particles initially observed by Pioneer 9, and much later at the earth, were generated by a solar flare on 2 August at 0324 UT at a heliographic longitude of 36° east of the sun-earth line, (the second flare on 2 August at 2040 UT would be classified as a contributor to the flux released by the first solar flare). The particle flux observed by the Pioneer 9 spacecraft was larger than the flux observed at the earth as would be expected from coronal propagation and gradient arguments. The solar proton time-intensity history of early August 1972 is shown in Figure 1. At the position of the earth the time-intensity flux profile is exactly as would be expected from a solar flare event east of the sun-earth line. The major particle event observed at the earth on 4 August was generated by a solar flare at 0621 UT, 9° east of the sun-earth line. From the aspect of the earth this is an eastern hemisphere event but near central meridian. From the aspect of Pioneer 9 this is a western hemisphere event 37° west of the sun-Pioneer 9 line.

Discussion. It is the opinion of these authors that the 4 August 1972 solar particle flux profile observed at the earth is the result of a sequence of unique and unusual occurrences: the result of a large injection of solar particles into a region of space where the converging interplanetary shock structures re-accelerated what was a substantial solar particle population into an extraordinary solar particle population.

The effects of shock acceleration can be seen in the Pioneer 9 data on 3 August shown by the flux level before and after the shock arrival at this spacecraft. In this case, the flux level increased approximately a factor of three. This is typical for strong shocks and has been observed many times.

At the position of the earth on 4 August, just prior to the solar flare at 0619 UT, two geomagnetic sudden commencements were recorded at the earth indicative of the passage of solar-generated shock waves from the flares on 2 August. When the flare of 4 August occurred at 0613 UT, the initial pair of interplanetary shocks had just passed the earth leaving the earth enveloped between the first shock ensemble and the much faster and more powerful shock generated by the 4 August flare. While the earth was enveloped between these two powerful converging shocks the flux observed at the earth was higher than that observed by Pioneer 9. This is the time of the particle flux paradox. The position in space that should be "well connected" to the solar flare location does not observe the largest solar particle flux. The position in space (in this case the earth) that observes the largest particle flux is to the west (in the sense of the solar rotation) of a radial from the solar flare location. This case of the spatial location west of the flare radial location observing the largest flux during a particle-shock phenomenon is an extreme example of the more general case investigated by Sarris et al. (1985) in the more distant heliosphere. Also Cane et al. (1988) have noted that for strong shocks, the largest observed fluxes are at positions west of the flare radial.

The time period when the earth was between the converging powerful interplanetary shocks is the time of the particle flux paradox and is the only time when there is anything extraordinary about the observed particle flux. During this time the earth observed particle flux was unusually high and had an extraordinarily hard spectra. This time period, from about 06 UT to about 24 UT on 4 August, is illustrated by the shaded portion of Figure 1. It is noted that the shock-acceleration phenomena that occurred during this time interval was sufficient to increase the maximum energy of the ions to several GeV and generate a ground-level event observable at high latitudes by cosmic ray neutron monitors.

After the converging interplanetary shock structure had passed the earth, the particle flux paradox ended, and the time-intensity profiles observed at both Pioneer 9 and the earth returned to classical behavior. The flux at Pioneer 9 (closer to the sun and "well connected" to the region of the solar flare) now exceeds the flux observed at the earth as would be expected from theory. The time intensity profiles now match very well the results expected from our proton prediction models. These observations also suggest that these unusually large flux events that are the result of shock acceleration of the ambient particle population can be limited in time and spatial extent.

In using the 4 August 1972 event to study major particle fluxes and worst case scenarios the question is often asked "Should an adjustment be made from the observed flux and fluence to a "worst case model" by invoking coronal gradients?". The argument for doing this is that the solar flare did not occur at the most favorable propagation location for measurements at the earth, and perhaps if this flare had been on the western hemisphere of the sun at a heliographic longitude of about 60° an even larger flux might have been observed at the earth. We will argue that the 4 August 1972 event is an example of interplanetary acceleration modifying the initial injection population of solar particles. A comparison of the particle flux measured by the Pioneer 9 spacecraft definitely does not support the "flux adjustment" hypothesis. The Pioneer 9 proton flux data on 4 August are definitely lower than the flux data obtained at the earth even though Pioneer 9 should be "well connected" to the solar flare and is

closer to the sun. The Pioneer 9 proton flux data on 4 August have been viewed with some skepticism precisely because the flux measured on Pioneer 9 is not what would be expected from the relative positions of the two measurement locations with respect to the flare on 4 August. However, the Pioneer data are considered valid for scientific analysis before the August 1972 events and are again considered proper for scientific analyses after the August 1972 events. We suggest that the Pioneer 9 data is also valid during the August 1972 events. These data also strongly suggest that the re-acceleration of the existing solar particle population by the shock is a local process, limited in both radial and heliolongitudinal extent.

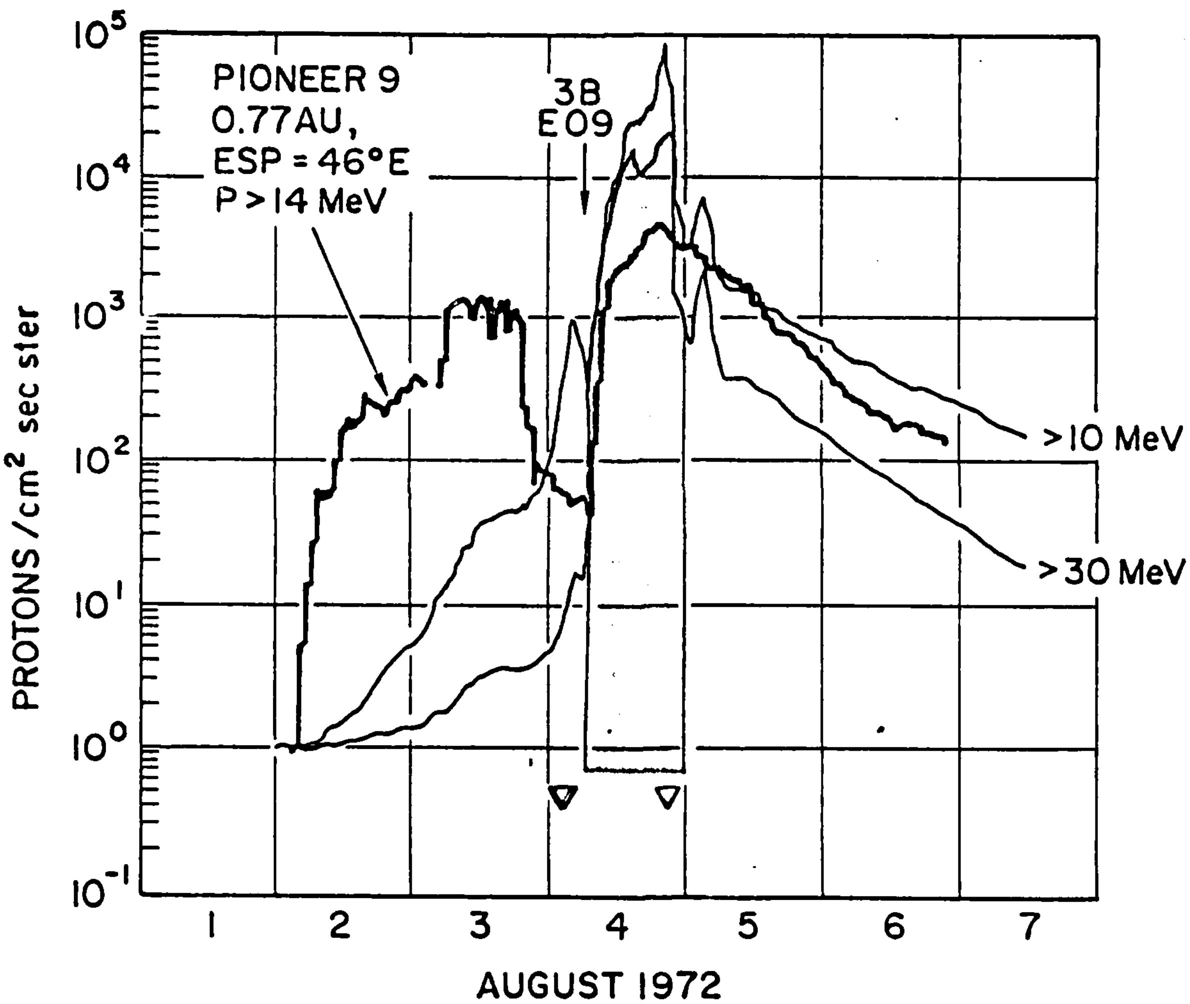

Figure 1. Illustration of the > 14 MeV proton flux observed at Pioneer 9 (heavy line) and the >10 and >30 MeV proton flux observed at the earth during August 1972. Note the extraordinary hard spectrum and high flux during the time when the earth was between the converging interplanetary shocks (the faster shock overtaking the initial shock ensemble).

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